ATMOSPHERIC ELECTRICITY.[1]

It is hardly possible to imagine that the first experimenter who obtained an electric spark sufficiently strong to produce a sensible sound should not at once have been struck by the fact that he was in the presence of thunder and lightning on a small scale. We find, indeed, in various writings from the early days of electrical machines a number of suggestions that the thunderstorm is an electrical phenomenon; but to Benjamin Franklin belongs the merit of having perceived that a direct experiment was needed to prove what so far was only a guess. In an article entitled "Opinions and Conjectures concerning the Properties and Effects of the Electrical Matter arising from Experiments and Observations made at Philadelphia, 1749," the following passage occurs:—

"To determine the question whether the clouds that contain lightning are electrified or not, I would propose an experiment to be tried where it can be done conveniently. On the top of some high tower or steeple place a kind of sentry-box, big enough to contain a man and an electrical stand. From the middle of the stand let an iron rod rise and pass, bending out of the door, and then upright 20 feet or 30 feet, pointed very sharp at the end. If the electrical stand be kept clean and dry, a man standing on it, when such clouds are passing low, might be electrified and afford sparks, the rod drawing fire to him from a cloud.

"If any danger to the man should be apprehended (though I think there would be none), let him stand on the floor of his box, and now and then bring near to the rod the loop of a wire that has one end fastened to the leads, he holding it by a wax handle; so the sparks, if the rod is electrified, will strike from the rod to the wire, and not affect him."[2]

The experiment suggested by Franklin was successfully performed in Marly (France), by D'Alibard, on May 10, 1752,[3] in London by Canton, in Spital-square, on July 20, 1752, and by Wilson, in Chelmsford, Essex, on August 12 of the same year. Franklin himself describes having used a kite in Philadelphia in a letter dated October 19, without giving the date of his observations. But this must be supplied in some passage which I have not been able to find, for Rosenberger ("Geschichte der Physik," vol. ii. p. 316) mentions that it was done in June.

Franklin's disbelief in the dangerous character of the experiment must have received a severe shock when he heard of the death of G. W. Richmann, who, in the year 1753, was killed by an electric discharge drawn from the clouds by means of a kite.

The thunderstorm is the most impressive effect of atmospheric electricity, though it is rivalled in beauty by the aurora, and in interest by the many phenomena of daily occurrence, which are only made perceptible to us by proper instruments. In a lecture delivered before this Institution on May 18, 1860, Lord Kelvin described the delicate electrical appliances constructed by him for the more accurate observation of atmospheric electricity. The problems then for the first time clearly stated, gave a powerful and still lasting impulse to the investigation of atmospheric electricity, and though no decisive answer can be given to all the questions raised in that lecture, recent researches have brought us somewhat nearer to their solution.

Observations which may be made every day and at every place have shown that the earth is electrified, whatever the weather may be. In the language of the older theories, which we cannot as yet altogether abandon, we say that the earth is covered with negative electricity, or, in modern phraseology, we express the same idea by the statement that we move about in an electrified field, that electric lines of force stretch through the air from the ground, from our bodies, and from everything which is exposed to the sky overhead. The strength of this electric field is not at all insignificant. If we wish to produce it artificially between two parallel plates kept at a distance of one foot, we should have to apply an electromotive-force sufficient—and sometimes more than sufficient—to light up the incandescent lamps which illuminate our dwellings. The electric force is comparatively weak in our country, but 50 volts per foot are constantly observed, and 100 volts are not uncommon; but in dryer climates the amount of the force may be considerably in excess of these figures.

If we fix our minds on the lines of force starting from the surface of the earth, we are at once led to ask, Where is their other end? Do they curve round and back again to earth? Do they end in the dust which everywhere surrounds us, or do they reach up to the clouds? Do they pass through the clouds and end where invisible particles separate the sunset red from the midday blue? Or, finally, do they leave the earth altogether, and form intangible bonds between us and the sun, the stars, the infinity of space? These are not idle questions, and we cannot be said to have solved our problem unless some definite answer is given to them. The last-mentioned view, propounded originally by Peltier, and latterly supported by Exner, is the simplest. If we could allow that the earth, once electrified negatively, could remain electrified for ever, the corresponding positive electrification being outside our atmosphere altogether, the chief difficulty of atmospheric electricity would be removed, and the normal fall of potential at the surface would be explained by the permanent negative electrification of the surface.

Unfortunately this view, to be tenable, has to assume that the atmosphere is a complete non-conductor to the normal electric stress, and this is known not to be the case. We know of several causes which break down the insulating properties of air. If two pith balls are electrified and repel each other, and a match be lit in their neighbourhood, the pith balls come together, showing that they have lost their charge, and consequently that the flame of the match has destroyed the insulating power of air. It is not only the flame itself which conducts, but also the gases rising from the flame.[1] The following experiment will prove this. In Fig. 1, A represents a metallic tube bent round at the upper end, and containing at its lower end a Bunsen burner in metallic contact with the tube, which is also connected to an electroscope. The tripod, T, which supports the tube, is insulated by blocks of paraffin. A Leyden jar, L, on a separate support, is placed so that the knob stands at about the level of the upper part of the tube, which acts as chimney to the flame. The knob of the jar may be a few inches away from the opening of the chimney, and not necessarily in a line with it. The experiment succeeds, although the gases rising from the burner may not come into contact with any part of the jar. The jar is charged, and care must be taken that no fibres of dust attach themselves either to the jar or chimney. I have found it convenient to join a piece of amalgamated zinc to the end of the chimney. Under these circumstances the charge of the jar will be found to leak across to the tube, and the leaves of it will diverge. If, as in Exner's form of electroscope, the leaves, on reaching a certain divergence, discharge by forming a

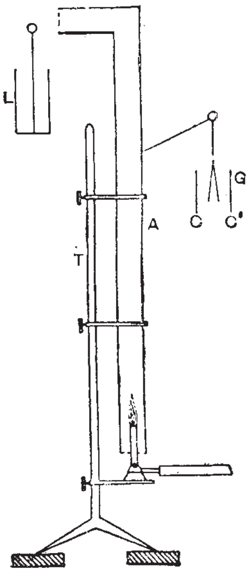

Fig. 1.

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[1] Discourse delivered before the Royal Institution of Great Britain, by Prof. Arthur Schuster, F.R.S.

[2] "Experiments and Observations on Electricity made at Philadelphia, in America," by Benjamin Franklin, LL.D. and F.R.S. (London, printed for David and Henry, and sold by Francis Newbery, 1769, p. 66.)

[3] *Ibid.*, p. 107.

[1] The most complete investigation of the conduction of gases rising from flames is contained in a series of papers by Giese (*Wiedemann's Annalen* vol. xvii.).

contact with earth-connected plates, C C′, the charging and discharging can be watched for a long time. It will be noticed that the flame, being altogether surrounded by a tube of the same potential, cannot be active in this case, but the conductivity must be due to the gas as it escapes from the chimney.

It follows from these experiments that every fire burnt on the surface of the earth, and every chimney through which products of combustion pass, act like very effective lightning conductors, and would consequently discharge, slowly but surely, any electrification of the surface of the earth. The peculiar immunity of factory chimneys against damage by lightning appears from statistics collected by Hellmann in Schleswig-Holstein,[1] for while 6·3 churches per thousand were struck, and 8·5 windmills, the number per thousand of factory chimneys was only 0·3.

Franklin was acquainted with the action of flames; he also discovered that no charge can be given to a red-hot iron ball, a fact which seems to have been forgotten until re-discovered in our own times by Guthrie. Franklin also tried the action of sunlight, but obtained no result. Had he performed the experiment with carefully-cleaned zinc, he would have anticipated one of the most striking of Hertz's discoveries. We now know that a negatively-charged surface will discharge into air when illuminated by strong violet light, and sunlight will be sufficient with specially sensitive materials. This action has been investigated in detail by Elster and Geitel, who have not, however, succeeded in obtaining results with sunlight acting on such bodies as we know the earth's crust to be made of. So far, then, we have no experimental evidence to include light as an active agent in the phenomenon of atmospheric electricity.

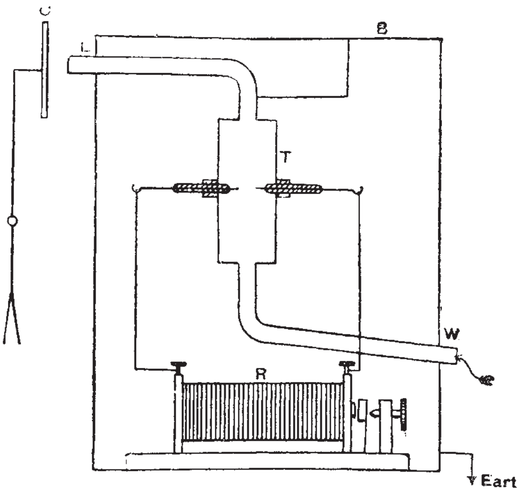

FIG. 2.

We possess in the electric discharge itself a very powerful, and probably very generally active means of breaking down the insulating power of air. Some of the experiments (*Proc. Roy. Soc.*, vol. xlii.) which I described some years ago to prove this, were objected to on the ground that it might not be the discharge itself, but the ultra-violet light sent out by the luminosity of the discharge, which was active. The following form of the experiment conclusively shows that the discharge acts independently of light.

In Fig. 2, R represents a Rhumkorff coil entirely surrounded by a metallic box, B, which is connected to earth. The terminals of the coil lead to two electrodes inside a metallic tube, T, which is also kept at zero potential. This tube is arranged so that a current of air can be blown through it. The air, on escaping through the tube, is made either to impinge on or to pass near a metallic plate connected to a charged electroscope. Under these circumstances, the electroscope is not discharged either by a current of air alone, or by the coil alone. But as soon as the air is blown through the apparatus while the sparks are passing and then made to impinge on the plate C, the electroscope is instantaneously discharged. The experiment succeeds when a plug of cotton-wool is inserted at W, to stop the action of the dust; but a plug of cotton-wool at the other end diminishes the action so much, that I am doubtful whether the effect then really exists there. I am, so far, not inclined to believe that the action is due to dust, but rather that the cotton-wool acts in increasing very considerably the interval which elapses between the time at which the spark acts and the time at which the sparked air passes out of the tube. The effect may be observed even though the tube L is lengthened by an addition of another piece 3 feet or 4 feet long.

Several phenomena, one of which had been known for a long time, can be explained by the fact that the electric discharge changes the condition of the gas into a state similar to that of gases rising from flames. It is mentioned, for instance, by Faraday that electric sparks are liable to succeed each other along the same path, and it is known that the same holds for lightning flashes, facts which themselves point to a higher conductivity of air along the path of the previous discharge. A curious instance of a similar effect is afforded by lightning conductors, which are sometimes put up to protect overhead leads used for conveying a high tension current. Owing to the obvious impossibility of connecting the leads directly to earth, a small air gap is interposed, the idea being that the air gap will act as an insulator for the current the leads are intended to carry, but that if during a thunderstorm the potential rises sufficiently high to be dangerous, equalisation may take place through the air gap to earth by means of a small spark. So far, the air gap answers its purpose, but as soon as a spark passes through the gap, it destroys the insulating power of the air, and the main current consequently takes a short-cut through the gap. At Pontresina, in the Engadine, lightning conductors put up in this way are so sensitive that a flash of lightning several miles away causes a small spark by induction, and instantaneously puts out every electric lamp in the town.

If we accept the view that an electric discharge destroys the insulating power of the gas, it follows that the outer regions of the atmosphere must conduct, for we have ample reason to suppose that electric currents are passing continuously through those regions. The aurora borealis in the arctic regions is, according to Nordenskiöld's observations, a permanent phenomenon, and the diurnal changes of terrestrial magnetism show that in our latitudes electric currents traverse the air above us. However small a conductivity we may assign to the atmosphere, the earth could not remain electrified inside such a shell of partially conducting gases. Lord Kelvin drew the same conclusion in the Royal Institution lecture, on the assumption that gases at much reduced pressures cease to insulate. We may leave it an open question whether the normal electric stress could in itself cause a discharge in the outer regions; but we cannot deny that under existing conditions these regions do not insulate, and Lord Kelvin's argument still holds good.

But the question of the ending of the lines of force—in other words, the location of the positive charge corresponding to the negative electrification of the surface of the earth—can only be solved by balloon or kite experiment, and we may briefly mention the more important results which have so far been obtained.

Observations made up to heights of about 1000 feet seem to indicate a strengthening of the electric field—*i.e.* the fall of potential per metre is greater at a height of, say, 200 metres than on the surface of the earth. The observations of Dr. Leonhard Weber (*Elektrotechnische Zeitschrift*, April 1888) bring out this point clearly. In one case the fall of potential at a height of 350 metres was found to be six times that at the earth's level. This increase is in itself not surprising, if we remember that every particle of dust raised from the ground must itself be negatively electrified, and probably the observed increase in the electric force is sufficiently accounted for by the presence of electrified dust.

Observations made at greater heights in balloons, on the other hand, seem clearly to indicate that this increase soon ceases, and that a diminution already takes place at moderate heights. Thus the observations of Dr. O. Baschin (*Meteorologische Zeitschrift*, September 1894) gave for the fall of potential in volts per metre the numbers 49, 28, 13 at heights of 760, 2400, 2800 metres respectively, and at a height of 3000 metres no measurable fall at all could be obtained. These observations were made in clear weather. The balloon afterwards passed over a layer of clouds, and strong electric effects were noticed. Similar observations had been previously made by others (Andrée, Le Cadet, and Bornstein), and though the subject is by no means exhausted, we may take it as provisionally established that the lines of force of the normal electric field of the earth end within the first 10,000 feet or 15,000 feet. This result is of great importance, for it shows that in fine weather there must be a layer of positively electrified air permanently above us. Currents of air in this layer must affect the field as we observe it, and possibly the daily period may be due to changes in the currents of air at a moderate height. A fact discovered by Exner is of importance in connection with this subject. Observing at three different places (in a field close to Vienna; in St. Gilgen, on the Wolfgangsee; and on the hills near Venice), he found that whenever there was a strong south wind, with a clear sky, the normal electric force was always increased, and sometimes considerably (*Wiener Akad. Sitzungsberichte*, vol. xcvi., 1887).

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[1] "Veroffentl. des Kgl. Preuss. Stat. Bureaus," 1886, p. 177, quoted by Bebber, "Meteorologie," p. 245.

The daily changes show, with few exceptions, a remarkable uniformity at different places. There are in general two maxima of potential—one at 8 or 9 o'clock in the morning, and one in the evening. The evening maximum is the most marked, while at some places, and especially near towns, the morning maximum disappears. The same general features of the daily variation have been found to hold at a number of European stations, at Cape Horn, Melbourne, and in the Northern Arctic regions. If the variation is separated into two—one having a period of 24 hours, and the other of 12 hours—the latter is found to agree in phase at widely different places on the earth's surface, while the former is found to vary to a much greater extent, and hence to be probably more affected by local circumstances. The remarkable researches of Hann have given a similar result for the diurnal variations of the barometer, and we may reasonably conclude that the semidiurnal variation of atmospheric electricity is connected with the same circulation in the upper regions of the atmosphere which shows itself in the corresponding changes of pressure.

In addition to the more regular periodic changes, the electric stress observed in fine weather shows marked differences on different days and at different seasons. With respect to these, the researches of Prof. Franz Exner (*ibid.*) have led to the important result that there is a close connection, direct or indirect, between the amount of aqueous vapour present in the atmosphere and the fall of potential observed at the surface of the earth. If p_0 be the pressure of aqueous vapour present in centimetres, Exner deduces the equation for electric force P

$$P = \frac{A}{1 + kp_0},$$

where $A = 1300$, $k = 13{\cdot}1$.

The formula agrees very well with observations in which the vapour pressure varied between 0·23 and 0·95, and it is especially to be remarked that it is the amount of vapour and not the humidity which determines the electric force. Observations made by Mr. E. Drory during a journey round the world fit in very well with Exner's formula, and observations made at such widely different places as Suez, Albany, Sydney, Colombo, and Penang showed a fall of potential practically identical with that calculated from the above formula, though the same constants were taken and the vapour pressure varied between 0·8 cm. and 2·2 cm.

Messrs. Julius Elster and Hans Geitel (*Wiener Akad. Sitzungsberichte*, vol. ci., 1892) have followed up this research. Their investigations have shown a satisfactory agreement with Exner's formula, if the mean values of a number of observations in which the vapour pressure is approximately the same, is considered. But individual numbers differ very widely from the mean, so that the formula cannot be used to predict the normal fall of potential on any particular day. There is, perhaps, nothing surprising in the great divergence of such individual results if it is considered that we only observe the moisture near the surface of the earth, but are ignorant of the total amount of water in the column of air over the district in which the observations are carried out. The same authors have shown that an equally good agreement can be obtained if, instead of the amount of aqueous vapour, we take the intensity of active radiation as the determining circumstance. The light might be supposed to act on the general surface of the earth, as it does according to Hallwachs' observations on a metallic body, dissipating a regular charge. There are some difficulties in the way of this explanation, the most serious being the absence of experimental evidence that sunlight actually does act in the manner indicated on any substance forming part of the earth's surface. It is impossible at the present time to enter more fully into this subject, but attention must be drawn to the very important indirect result, that there seems to be a connection between ultra-violet radiations and the amount of aqueous vapour present in the air.

The phenomena of atmospheric electricity have been studied at the mountain observatory established on the "Sonnblick," in Salzburg, at a height of 3100 metres.

The important result has been established that the electric force is singularly constant. The great differences observed at low level between the electric field in summer and winter, or on dry and wet days, seems to be completely absent, and these facts tend to support the conclusion derived from balloon observation, that the positive ends of the lines of force are situated at a height of something like 10,000 feet.

Brief allusion must be made to some of the causes which alter to a marked extent the normal fall of potential. As the surface of the earth is negatively electrified, it follows that dust carried up by the wind must be electrified, and it is found, indeed, that in violent dust storms the laws of force near the surfaces are altogether distorted and reversed in direction. Werner Siemens (*Pogg. Ann.* cix., 1860; *Meteorologische Zeitschrift*, 1890, p. 252) could, while standing on the top of one of the pyramids during a strong wind, charge an improvised Leyden jar sufficiently to obtain strong sparks. A casual observation of Elster and Geitel (*Ziele und Methoden*, p. 11) may prove significant. On March 7, 1889, the temperature in Wolfenbüttel was rising from − 10° C. to + 2° C., a cirrus layer covering the sky. The fall of potential changed in the course of four hours from 1302 volts per metre to − 1200 volts, that is, from a very exceptionally high fall to an equally strong gradient in the other direction. Although the atmospheric circumstances were anomalous, they seem in themselves not sufficient to account for the anomalous electrical effects, and the authors suggest that a possible explanation may be found in a violent dust storm which on the previous day was observed in Alexandria.

Fogs are generally found to increase the normal fall considerably, so that the drops of water must be taken as positively electrified.

Waterfalls considerably disturb the electric condition of the air in their neighbourhood, the air surrounding the fall being charged negatively, sometimes to considerable distances.

Whether clouds in themselves are always electrified is very doubtful; they no doubt disturb and generally weaken the fall of potential at the earth's surface, but this may only be due to a displacement of the positively-electrified layer which balloon observations have shown to exist at a height of from 10,000 feet to 20,000 feet. While a cloud discharges rain, the electrical effects in the neighbourhood of the place are the same as that in the neighbourhood of a waterfall. The explanation is probably the same in the two cases, and by means of experiments, alluded to further on, we may reproduce the negative electrification of air under similar circumstances.

Measurements of the electrification of falling rain or snow, simple as they appear at first sight, are beset with very serious difficulty. We owe the most complete investigation on the point to Messrs. Elster and Geitel (*Wiener Sitzungsberichte*, vol. xcix., 1890). They find no regularity in the electrification, though positive signs slightly preponderate with snow and negative signs with rain.

The approach of a thunderstorm announces itself by characteristic cumuli clouds, and the general atmospheric condition favourable to their formation is felt by many persons of nervous temperament. Many of us are accustomed to hear that "there is thunder in the air." Whatever the special feeling of "thunder" may be due to, it cannot be an electrical effect, for electrical instruments delicate enough to detect a small fraction of the normal force, give no indications of the approach of a thunderstorm, and it is only when the cloud has begun to discharge rain or hail that strong electrical effects are noticed. During the thunderstorm the electroscope is, of course, much disturbed, and there are frequent and violent reversals of its indications.[1] The fact that no effects are observed at the surface of the earth during the approach of a thunder-cloud does not prove that there is no electrical separation, for we may imagine two oppositely electric layers at different levels producing a strong electric field between them, but only weak effects outside. That some such things may possibly occur is indicated by observations made in mountain districts, where violent electrical disturbances are observed previous to the formation of clouds (Trabert, *Meteorologische Zeitschrift*, 1889, p. 342). The cumulus cloud, from which the lightning strikes out, is nearly always associated with a cirrus layer above it, and the flash occurs more frequently upwards or sidewards between the clouds than down to earth. Under such circumstances it is clear that instruments on the surface of the earth can only very partially indicate the nature and distribution of electrical stress in the neighbourhood of the cloud.

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[1] Weber, *Elektrotechnische Zeitschrift*, vol. x.; Elster and Geitel, "Ueber einige Ziele und Methoden Luftelektrischer Untersuchungen," Wolfenbüttel, 1891.

Thunderstorms seem always to be connected with a vortex motion, and meteorologists distinguish two kinds of thunderstorms. The first kind forms in the outlying portions of a large cyclonic system. The storms which occur in winter are mostly of this nature, and the vortex necessary for its formation is of the nature of a secondary disturbance. The thunderstorm which forms in summer, on the other hand, makes its own vortex, and is of a much more local character than that which is produced round a previously established barometric depression. The summer storm is much influenced by the character of a district. There are certain configurations apparently favourable to its formation, as is clearly brought out by the charts which have been made representing their frequency.

The route travelled over by the storm is affected by mountain ridges, and rivers also seem to offer a peculiar impediment. Many of them are brought to an end either along their whole front, or only part of it, when they reach the banks of a large river.[1]

Some curious problems are presented by the detailed structure of lightning flashes. Although these lie outside the range of the present lecture, reference must be made to the very beautiful photographs of lightning flashes taken both in this country and abroad. The ordinary forms which lightning takes are familiar to all; but a good deal of mystery still surrounds the so-called globular lightning. The manner in which this form appears is best described in the words of eye-witnesses.

Dr. A. Wartmann gives to the Physical Society of Geneva the following account of what he saw:[2]—"At half-past six o'clock in the evening I drove from Versoix to Genthoud. On the Malagny road I heard the coachman say he did not know where he was. His eyes were so much fatigued by the frequent and intense lightning discharges, that he was blinded, and could not, even in the intervals, see the road, in spite of the good lanterns alongside. I stepped on to the box and took the reins. We had barely passed the principal gate of the grounds of Dr. Marcet, when I became conscious of a bright and lasting luminosity behind me. Thinking it was a fire, I turned round, and saw, at a distance of, roughly, 300 metres, a ball of fire of about 40 cm. diameter. It travelled in our direction with a velocity about equal to that of a bird of prey, and left no luminous trail behind. Just as the ball had overtaken us, about 24 metres to our right, it burst with a terrific noise, and it seemed to me as if lines of fire started from it. We felt a violent shaking, and remained blinded a few seconds. As soon as I regained power of distinguishing objects, I saw that the horses had turned at a right angle to the carriage, with their chests in the hedge, with drooping ears and all signs of great terror. I returned on the following day to the place where I had seen the ball explode, but could find no sign of any damage. At a distance of 100 metres I found that a group of three trees, bordering a wood, had their upper branches singed, but it is not possible to say whether this was due to the discharge which I had seen."

The following is a translation of an account given by Mr. H. W. Roth (*Meteorologische Zeitschrift*, 1889, p. 231):—"During the thunderstorm of May 19, 1888, at about 6 p.m., a flash of lightning took effect which seems to me remarkable from a physiological point of view. The dealer Werner, from Ellerbruch, and his son (sixteen years old), with a one-horse conveyance containing rags, were on the road which leads from here to the village of Ottensen, about three miles away in a south-westerly direction. The father had been left a little behind, and the son was occupied in giving bread to the horses, when he found himself suddenly surrounded by light, and noticed a fiery ball, about the size of his fist, moving towards him along the back of the horse. Then he lost consciousness. He felt no concussion. The father, on approaching, saw the horse's limbs still contracting, and at first he thought his son was dead, but succeeded, after considerable efforts, in bringing him back to life in about three-quarters of an hour. The horse was dead."

Some curious statistics have been collected, especially in Germany, as to the damage done by lightning flashes. That damage seems to have increased to an enormous extent within the last fifty years, and although in cases of this kind statistics may easily be at fault, there seems no doubt about the reality of the fact, which may find an explanation in the partial cutting down of forests in those parts where thunderstorms chiefly occur. When lightning strikes into forests, it selects certain trees by preference. Thus, in the principality of Lippe, taking the percentage of beeches struck by lightning as unity, that for other trees is as follows:—Oak 48, spruce fir 5, Scotch fir 33.

The St. Elmo's fire, a continuous discharge from points and sharp angles, is often observed on board ship and in mountain districts during a storm. Its appearance was considered a sign of the approaching end of the lightning, and was looked upon with favour by the ancient sailors in the Mediterranean Sea, who gave to it the name of Castor and Pollux. There was another appearance called Helena, a bad omen, which by many is believed to have been another form of the St. Elmo's fire, and the present name has been stated to be a corruption of the word Helena. Some support is given to this view by the fact that the Emperor Constantine built a castle in the Pyrenees, which he named after his mother, Helena, and this castle seems to be referred to occasionally as St. Elne or St. Elme. But it is much more probable, as argued by Dr. F. Piper (*Pogg. Ann.*, vol. lxxxii. p. 317), that the word is derived from St. Erasmo, a bishop who came from Antiochia, and suffered a martyr's death at the beginning of the fourth century. He seems to have been specially considered the patron of Italian sailors. Churches and castles in Naples and Malta were called St. Erasmo and St. Ermo, and Ariosto describes St. Elmo's fires as St. Ermo's fires. The electric discharge which goes under this name has a different appearance according as it is the positive or negative electricity which escapes, and both kinds occur with about equal frequency.

Although we have not yet arrived at any satisfactory theory of atmospheric electricity, some progress has been made, and this account would not be complete without a short account of the views taken by men of science on the subject. The number of theories proposed is very considerable. Dr. Suchsland,[1] in a pamphlet published in 1886, gives an account of twenty-four, to which he adds one—his own. The year 1884 alone has given birth to four theories.

We may group the theories according to the origin they assign to the source of energy which is involved in the formation of the electric field. All the work we can perform is either derived from the sun or from the earth's rotation. There is, as far as I know, only one theory—that of Edlund—which makes the earth's rotation in space responsible for the separation of electricities in the atmosphere. But Edlund's views are not tenable in theory, and, even granting his deductions, the normal fall of potential should, according to the views of the author, have a different sign in the polar and equatorial regions, which is contrary to the observed fact. This theory does not, however, exhaust the possibility of explaining atmospheric electricity as a phenomenon of electromagnetic induction, and it is not disproved that in some form or other the rotation of the earth's magnetic field may play a part in the origin of the electric field. The theories which take solar radiation as the source of the energy divide themselves into several groups. We may think of a direct thermo-electric or actinic action, but there is, so far, no experimental support to such views. One of the earliest and most natural suppositions is the belief in evaporation as a source of electrification. This was Volta's theory, and experiments have at various times been produced in its support; but, so far, no one has been able to invalidate Faraday's conclusion that whenever electrification seemed to appear as a consequence of evaporation, it was really due to secondary causes, such as the friction of the liquid spray against the sides of the containing vessel. Rejecting Volta's theory, there is nothing left but the belief in some form of contact or frictional electricity either between drops of water and air, or water and ice, or any two of the various bodies present in the atmosphere. The possibility of contact electricity between a solid or liquid and a gas, is not quite easy to submit to the test of experiment. If we rub two solid bodies together, we may, by separating them, investigate the electric field produced; but, supposing we have a drop of water surrounded on all sides by air, the water may be covered with an electric layer of, say, positive electricity, the air in contact with the water with the opposite kind, and it is not at all clear how we could experimentally demonstrate the difference of potential between the air and the drop which is thus produced. A current of air flowing past the drop might carry away some of the negative layer, and in this way an electric field may be established while clouds are forming, but the conditions necessary for an experimental demonstration would be very difficulty to realise. Two methods have been devised which practically demonstrate some form of contact electricity between gases and water.

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[1] Bebber, "Meteorologie,' p. 255; Bornstein, *Archiv der Seewart*, viii., 1835.

[2] *Arch. des Sci. Phys. et Nat.* (3) vol. xxi., 1889. The above account is translated from the *Meteorologische Zeitschrift*, 1889.

[1] "Die Gemeinschaftliche Ursache der Elektrischen Meteore und des Hagels," H. W. Schmidt, Halle-a.-S.

Lenard, wishing to imitate the electric field observed in the neighbourhood of waterfalls, has established by careful experiment a number of important facts, which are all consistent with the following explanation. If we imagine two oppositely electrified layers at the surface of a drop of water such as has been referred to, and if the drop falls on to a layer of the same liquid, or if similar drops impinge on each other, the difference of potential produced by the fusion of the surface layers becomes greater than is consistent with equilibrium. For, taking the case of drops falling into a mass of water contained in a cylindrical vessel, the extent of surface between air and water is not increased by the falling drops, and we must imagine that surface to be already covered with a sufficient electrical sheet to establish the required difference of potential, The electrification of the drops is, therefore, not wanted, and a change in the distribution takes place. The natural supposition would be, that this equilibrium would be restored very quickly through the surface of the water, but a certain time seems to be required for this. Meanwhile, the strong current of air which in Lenard's experiments is brought down with the water drops carry some of the electricity away, the water remaining positive. More recent experiments of Lord Kelvin's, with air bubbling through water, point similarly to contact forces between gases and liquids, and in these experiments also it appears that a considerable time is required to establish electric equilibrium between a gas and a solid. Lenard finds very important differences caused by small impurities in the water, the water acting much more strongly when it is pure. If it contains as much salt as is contained in the sea, the effect is reversed, and the air becomes positively electrified. The explanation which is given above is practically that of Lenard, whose observations have been confirmed and further extended by Prof. J. J. Thomson. These experiments, no doubt, account for the behaviour of air in the neighbourhood of waterfalls, and they probably also explain the negative electrification of air in the neighbourhood of districts in which rain is falling. The strong positive electrification of mist may also be due to the same cause.

There seems to be no doubt that the formation of a cloud is often accompanied by electrical effects. A few years ago, descending from the Dent Blanche, I found myself, after sunset, at a height of about 12,000 feet. A current of air was apparently blowing up the valley which stretches from Evolena towards Ferpecle, and I could observe a cloud condensing below me at a height a little below the snow-line. As night came on and we continued our descent over the glacier and down the valley, a series of electric discharges were noticed between the cloud, which was lying in a deep-cut valley, the sides of the mountain, and the blue sky overhead. Here the moist air was evidently streaming through the cloud, depositing its moisture in the form of drops, and it seemed the most natural explanation at the time that the air left the cloud in an electrified state.

But while by means of experiments we have been able to produce some of the phenomena of atmospheric electricity, we have other important effects which cannot be accounted for in so simple a way. The electric discharges during a thunderstorm give evidence of electric fields, which could hardly be explained by contact electricity between drops of water and air alone. The fact that thunderstorms are nearly always connected with the formation of hail, and Faraday's experiments showing that water rubbing against ice becomes negatively electrified, is made use of in the theories of Sohnke and Luvini. It is quite likely that there is some truth in these theories. Their weak point lies in the difficulty of seeing how particles of ice and water can be first sufficiently mixed to allow of friction, and then become sufficiently separated to produce an electric field of such magnitude as we know must exist in a thunder cloud.

It is to be remarked, however, that the laws of contact electricity must be applicable to gases as well as to solids, and that if water becomes positive when rubbing against air, and negative when rubbing against ice, there must be a strong contact difference between ice and air. In other words, it does not matter whether there is direct friction between ice and water, or whether the air forms an intermediate body. We may imagine air rising through a cloud containing drops of water negatively electrified, and then passing through an ice cloud having its negative electricity increased, thus leaving the ice and water particles at a difference of potential which may, by a fusion of the drops, increase sufficiently to produce a lightning discharge. This seems to me the most plausible theory which, in the present state of our knowledge, can be formed. As regards the permanent negative charge of the earth's surface, the time has not yet arrived for forming a definite opinion. Although we know that the earth, once electrified, would gradually lose its charge into the atmosphere, yet we can express no opinion as to the rate at which the loss is going on. That loss may be exceedingly slow, and consequently equilibrium might be attained by a very small preponderance of negative electricity brought back to its surface through some cause or other. Rain, as has already been mentioned, is more frequently electrified negatively than positively in our own climate, and though we do not know how far this holds in the tropical belt, it is at any rate possible that the surface of the earth may in this way alone make up for the loss. We may also reasonably think that Lenard's observation on salt water may account for the permanent charge. Every wave that breaks into spray under the action of a strong wind would leave the water negatively electrified, the air carrying away the positive charge. It would be of great interest to possess observations on atmospheric electricity on board ship while waves are breaking in the neighbourhood. So far we have only Exner's observations to guide us, who found, while observing at Lavinia, in Ceylon, that the spray from breaking waves affected the indications of the electrometer, proving its positive electrification (*Wiener Akad. Sitzungsberichte*, vol. xcviii.).

But although the loss of electricity from the earth's surface may be very slow, it is equally possible that it is considerable. We shall not be able to treat this question satisfactorily until we have some clearer notion of the causes of the aurora. We know that the aurora implies electric currents, and the circuit of these currents may lie completely within the earth's atmosphere, and have nothing to do with the observed fall of potential near the ground. It is also possible that the body of the earth forms part of the electric circuit, and if that is the case, there must be across different parts of the surface an outward and inward flow of positive electricity. Such a discharge could not fail to influence the phenomena we have discussed, and it seems probable that we should have some evidence derived from observation if the aurora was always accompanied by discharges through the earth's surface. Except in the polar regions, these auroræ do not seem to affect the normal fall of potential. There is a third view we may take as to the circulation of electric currents indicated by the aurora: the return current may take place in space outside the earth's atmosphere. A good deal might be said in favour of this view, and the rotation of the earth's magnetic field in space might be a sufficient cause for the production of these currents; but this is not the place to enter further into this question.

Calculations made from observation on the height of the aurora have generally resulted in an altitude of from 100 to 200 miles, except in the polar regions, where the aurora seems occasionally to descend to a much lower level. It has also been noticed that auroræ are associated with certain bands of cirrus clouds, and this seems to indicate that although the luminous phenomenon is sufficiently intense to be observed at only great heights, yet the electric phenomena may descend to the level of the cirrus.

As regards the connection between the aurora and the sun-spot period, further observations in the polar regions are needed. On the one hand, we have Paulsen's[1] statement, derived from observations in Greenland, to the effect that the greatest number of auroræ are seen when sun-spots are at their minimum, that is, at a time when in our own latitudes the number is smallest; and, on the other hand, we have Nordenskiöld's observations, which seem to point in the opposite direction. In a publication which contains much important matter on the geographical distribution and form of the aurora borealis, Nordenskiöld contrasts the appearances he has observed in the *Vega* during the winter of 1878–79, passed in the Behring Straits, with that previously observed in 1872–73 to the north of Spitzbergen. According to this author, the auroræ, during the minimum sun-spot period in 1878–79, were "hardly worthy of his notice by the side of those observed in 1872–73." But although only faintly luminous, the auroræ of 1879 were persistent and regular in shape. They did not affect the magnetic field, and seem to show a regular and continuous, though weak, electric discharge. The are and streamers in 1872 were much more brilliant and much more irregular. Some objection may be raised against these observations, in so far as they refer to different places, and local circumstances may have affected the phenomenon; but in the face of the very careful description he gives us, we cannot as yet accept Paulsen's results without further confirmation.

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[1] Paulsen, "Danske Videnskab. Selskabs Forhand.," 1889. (I have not seen the original memoir, but only an abstract in the *Jahrbuch der Astronomie und Geophysik*, 1890.)

The problem of atmospheric electricity, like that of terrestrial magnetism, presents special features in the arctic regions, and until we possess a greater number of observations in those little accessible parts of the earth's surface, many important problems cannot be satisfactorily solved. Arctic and antarctic expeditions are of interest to scientific men, not because they care much whether we get a few miles nearer the pole, but because a well-conducted party collects invaluable information on its journey. Although much remains to be done in the regions surrounding the north magnetic pole, our knowledge in the southern hemisphere is almost disgracefully inadequate, and it is to be hoped that before long a well-equipped expedition may fill up to a certain extent the large gaps in our electrical and magnetical knowledge which at present stop so many of our researches.

But although investigations to be conducted in the arctic regions are of primary importance, we may do much nearer home in extending and completing existing information. Instrumental appliances and methods of observation, originally put into a satisfactory state by Lord Kelvin, have been improved, especially by Mascart, Exner, Elster, and Geitel. One of our most crying wants at present is a series of continuous observations by means of self-registering instruments in places where the neighbourhood of a town, or other local circumstances, do not interfere with the normal changes. The Greenwich Observatory, to which we look for help in such matters, is placed in the difficulty that the daily variations there observed are markedly different from those in the majority of places, and it is probable that the nearness of London is fatal to any generally useful series of observations of atmospheric electricity being conducted in our national Observatory.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

THE annual general meeting of the Association of Technical Institutions will be held at the Goldsmiths' Hall on Friday, the 24th inst.

THE Senate of University College, Liverpool, on the joint recommendation of Profs. Lodge and Hele Shaw, have appointed Mr. Alfred Hay, B.Sc., of University College, Nottingham, to the Lectureship on Electrotechnics, vacant by reason of the election of Mr. F. G. Baily to the chair of Electrical Engineering at the Heriot-Watt College, Edinburgh.

MR. L. F. GOLDSTAND has presented the Royal Agricultural College, Cirencester, with the sum of £200 for the institution of three silver medals annually, to be awarded according to results of the final examination for the diploma, at the discretion and decision of the Principal. The donor has requested that the medals be styled the "McClellan," the "Harker," and the "Goldstand," respectively; and the Principal, on behalf of the Governing Body, has accepted and ratified the donation.

THE eighth annual report, just published by the National Association for the Promotion of Technical and Secondary Education, is a mine of statistical and other information referring to the development of educational organisation in Great Britain. Substantial progress is recorded in the work of technical education; and it appears that of the £744,000 annually available in England alone, £600,000 is being spent on education. In the year covered by the report, 7252 scholarships and exhibitions, of the total yearly value of £40,598, were offered by thirty-seven counties. A large section of the report is devoted to summarising the recommendations of the Royal Commission on Secondary Education.

AMONG recent appointments and nominations abroad, we notice the following:—Dr. Hürthle to be Extraordinary Professor of Physiology at Breslau; Dr. N. Busch to be Director of the Botanic Garden of the University of Dorpat; Dr. K. G. Huefner, Professor of Organic and Physiological Chemistry at Tübingen, to succeed the late Prof. Hoppe-Seyler at Strassburg; Dr. Bauschinger, of Munich, to succeed the late Prof. Tietjen as Extraordinary Professor of Astronomy at Berlin; Dr. Anton F. v. Eiselsberg, Professor of Surgery at Utrecht, to be Prof. Braun's successor at Königsberg; Dr. H. Nichols to be Lecturer in Psychology in the Johns Hopkins University, Baltimore.

SCIENTIFIC SERIALS.

The Quarterly Journal of Microscopical Science for August 1895 contains: On the variation of *Haliclystus octoradiatus*, by Edward T. Brown (plate 1). Some 154 specimens were examined, 120 of these were perfectly normal but 34 afforded either cases of congenital variation, or showed regeneration of organs after destruction or injury. Most of the abnormal forms are figured.—On the collar-cells of Heterocœla, by George Bidder (plate 2). Observations were made on *Leucandra aspera, Sycon raphanus, S. compressum*; this last was found best suited for examination under high powers during life, its collar-cells are among the largest, if not as large, as any known. The protoplasm of these cells is in life greenish, and they have nearly the form and relation to each other of full corn-sacks standing side by side in a granary. The living collar is invariably an almost perfect cylinder, very little constricted at its base. As to Sollas's membrane, the statements of Vosmaer and Pekelharing, which the author once thought erroneous, he now confirms, there is no normal union of the collars, the membrane is only to be met with in "paraffin sections."—The metamorphosis of Echinoderms, by Henry Bury (plates 3–9). With the view of clearing up some of the differences in observation and opinion of the more recent observers of the metamorphosis of this group, the author has worked out as far as possible the metamorphic changes of at least one form of larva in each of the five classes of Echinoderms; for reasons given, the metamorphosis of Synapta is written in greater detail than that of the rest. As to the relation of the Echinodermata to the Enteropneusta, "there seems to be a chain of evidence of their connection, which though not indeed conclusive—that embryological evidence alone can never be—is at least as strong as that which binds together any two of the great subdivisions of the animal kingdom."—A criticism of the cell-theory; being an answer to Mr. Sedgwick's article on the inadequacy of the cellular theory of development, by Gilbert C. Bourne. The article of Prof. Sedgwick here criticised appeared in the *Q.J.M.S.* for November 1894.

The number for November 1895 contains:—On the distribution of assimilated iron compounds, other than Hæmoglobin and Hæmatins, in animal and vegetable cells, by Dr. A. B. Macallum (plates 10–12). After some preliminary remarks on the special literature of the subject and references thereto, the author details his methods of study. This portion of the memoir is very instructive, not only for the facts recorded, but for the hints given; chlorophyll yields no evidence that it contains iron, and it is mentioned incidentally that species of Monotropa remain colourless when fixed in solutions of corrosive sublimate. The greater part and sometimes the whole of the assimilated iron in the cells of the higher forms of animal life is held in the nucleus, in the chromatin of which it is chiefly found, and the same is true of the nuclei of all the higher vegetable organisms; it is rarely found in the cytoplasm of the cells, but full details of such occurrences are given. An important section is devoted to the occurrence of assimilated iron in special forms of life, such as in protozoa, fungi, bacteria, and the Cyanophyceæ.—On the structural changes in the reproductive cells during the spermatogenesis of Elasmobranchs, by J. E. S. Moore (plates 13–16). The author establishes a long series of structural homologies found before, during, and after the synaptic phase in the repro-